Fermilab Drift Tube Linac Revisited

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Abstract

Using the PARMILA code running under PC-WINDOWS, the present performance of the Fermilab Drift Tube Linac has been analyzed in the light of new demands on the Linac/Booster complex (the Proton Source).

Introduction

The Fermilab Drift Tube Linac (DTL) was designed in the sixties as a proton linac with a final energy of 200 MeV and a peak current of 100mA. In the seventies, in order to enable multi-turn charge exchange injection into the Booster, the ion source was replaced by an H- source with a peak beam current of 25mA. Since then the peak beam current was steadily increased up to 55mA. In the early nineties, part of the drift tube structure was replaced with a side-coupled cavity structure in order to increase the final energy to 400 MeV. The original and still primary purpose of the linac is to serve as the injector for the Booster. As an added benefit, the Neutron Therapy Facility (NTF) was built in the middle seventies. It uses 66MeV protons from the Linac to produce neutrons for medical purposes. The Linac/Booster complex was designed to run at a fundamental cycling rate of 15Hz, but beam is accelerated on every cycle only when NTF is running. Until recently the demand from the High Energy Physics program resulted in an average linac beam repetition rate of order 1 Hz. With the MiniBoone experiment and the NuMI program, the demands on the Proton Source have changed, with emphasis on higher beam repetition rates up to 7.5Hz. Historically the beam losses in the linac were small, localized at one spot, so activation was not an important issue. With higher beam rate, this has the potential to become the dominant issue. Until today all tuning in the linac and Proton Source was governed by two goals: to maximize the peak beam current out of the linac and to minimize the beam losses in the linac. If maximal peak current from the linac is no longer a primary goal, then the linac quadrupoles can be adjusted differently to achieve different goals.

Numerical Simulation

I am aware of two papers [1,2] from the early years of Fermilab that describe numerical simulations of the DTL linac. In both cases a small number of non-interacting particles was used. The Linac group has a PARMILA input file which was running on the VAX computers and which was generated by J.E. Stovall [3] from LANL. This input generates a table of drift tubes as built, and it is based on a so-called COEF parameter that describes the accelerating property of the tanks. PARMILA runs using this input were successfully used to study buncher efficiency and capture of 750 keV DC beam in DTL Tank 1 [4]. These studies were done with a few thousand interacting particles.

A new version of PARMILA that runs on a PC under Windows has slightly different input format. The COEF input parameter is not used any more; it is replaced by SFDATA. To construct SFDATA parameters I have used old printouts that contain drift tube tables based on which the linac was built.

For future reference I am listing relevant polynomial coefficients in the tables that follow.

Tank1-a

	T	S	TP	SP	G/L	Emax	ZTT
A0	-0.18562	0.7557	0.16011	-0.08813	0.17455	6.09728	-26.19765
A1	34.70829	-6.59323	-2.3526	5.47904	0.97385	-13.17512	1730.15012
A2	-426.99888	37.58441	13.21805	-71.97299	0	0	-10293.0702
A3	1851.37944	0.0	0.0	322.88453	0	0	0

Tank 1 is described with two tables. This tank has 56 cells; the first 18 cells have a bore radius of r=1.25 cm. The rest of the drift tubes have a bore radius of r=2.0 cm. Tank1 is the only tank that has linearly ramped electric field, with 1.6 MV/m in the first cell and 2.305 MV/m in the last cell.

Tank1-b

	T	S	TP	SP	G/L	Emax	ZTT
A0	0.2608	0.76204	0.13852	0.00158	0.17680	6.54660	-26.19765
A1	12.10798	-6.33648	-1.60736	1.23576	0.95165	-22.62104	1730.15012
A2	-88.84793	44.47632	9.89492	-9.52347	-0.36369	56.88132	-10293.0702
A3	215.72371	-96.6965	-18.51997	25.68670	0	0	0

Tank2

	T	S	TP	SP	G/L	Emax	ZTT
A0	-0.18562	0.7557	0.16011	-0.08813	0.17455	6.09728	-26.19765
A1	34.70829	-6.59323	-2.3526	5.47904	0.97385	-13.17512	1730.15012
A2	-426.99888	37.58441	13.21805	-71.97299	0	0	-10293.0702
A3	1851.37944	0.0	0.0	322.88453	0	0	0

Tank3

	T	S	TP	SP	G/L	Emax	ZTT
A0	-0.18562	0.7557	0.16011	-0.08813	0.17455	6.09728	-26.19765
A1	34.70829	-6.59323	-2.3526	5.47904	0.97385	-13.17512	1730.15012
A2	-426.99888	37.58441	13.21805	-71.97299	0	0	-10293.0702
A3	1851.37944	0.0	0.0	322.88453	0	0	0

Tank4

	T	S	TP	SP	G/L	Emax	ZTT
A0	-0.18562	0.7557	0.16011	-0.08813	0.17455	6.09728	-26.19765
A1	34.70829	-6.59323	-2.3526	5.47904	0.97385	-13.17512	1730.15012
A2	-426.99888	37.58441	13.21805	-71.97299	0	0	-10293.0702
A3	1851.37944	0.0	0.0	322.88453	0	0	0

Tank5

	T	S	TP	SP	G/L	Emax	ZTT
A0	-0.18562	0.7557	0.16011	-0.08813	0.17455	6.09728	-26.19765
A1	34.70829	-6.59323	-2.3526	5.47904	0.97385	-13.17512	1730.15012
A2	-426.99888	37.58441	13.21805	-71.97299	0	0	-10293.0702
A3	1851.37944	0.0	0.0	322.88453	0	0	0

The Linac has six different types of quadrupoles. The following summary is from a memo written by Cy Curtis to S. Ohnuma.

Type	Length(in)	Eff.Len(in)	Bore Rad.(cm)	Turns/pole
I	1	1.36	1.1	21
II	1.25	1.61	1.1	21
III	1.75	2.22	1.45	19
IV	2.75	3.23	1.45	19
V	4	4.48	1.7	12
VI	6	6.48	2.2	11

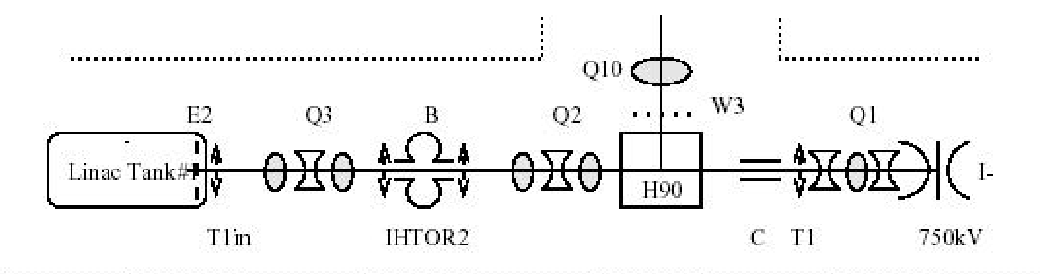
The excitation is defined as $B' = 8\pi \cdot 10^{-4} N \frac{I}{r^2} = kI$, where B' is in kG/cm, N in turns/pole, I in Amps and r in cm. The quads are arranged in the following way in the linac.

Type I	Tank1, Q1 to Q8
Type II	Tank1, Q9 to Q18
Type III	Tank1, Q19 to Q34, Q57 (the last quad), Tank2, Q1
Type IV	Tank 1, Q35 to Q56
Type V	Tank 2 (except Q1), Tank 3, Tank 4
Type VI	Tank 5

In summary, the input file for beam dynamics simulations was built using the following criteria and information:

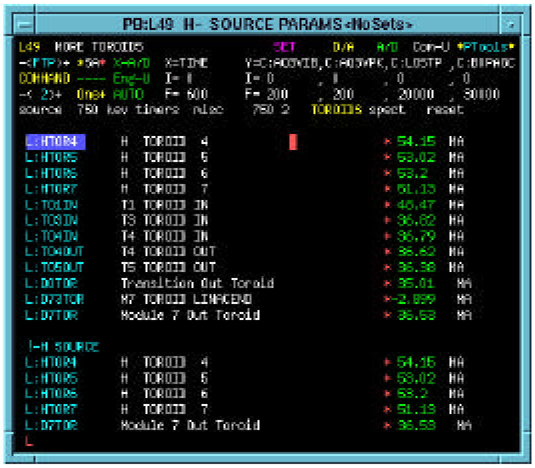
- Parmila input “designs” linac with cell lengths as built.
- Quadrupole lengths and arrangements are adjusted with the CHANGE command.
- The gradients of quads are calculated using current readbacks as reported by ACNET.
- At the entrance to Tank 1 there is a set of emittance probes. These probes were used to measure beam ellipses and adjust beam input parameters.
- The energy spread was measured at the exit of the 750keV column.

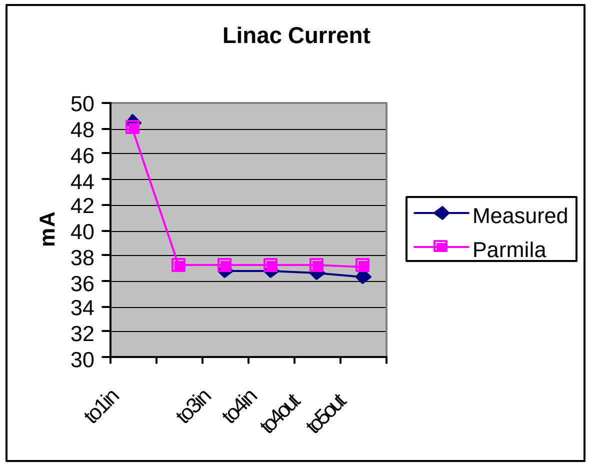
In the present simulation the beam starts at the center of the 90-degree magnet and is transported through two triplets and the buncher cavity as shown in Fig. 1.



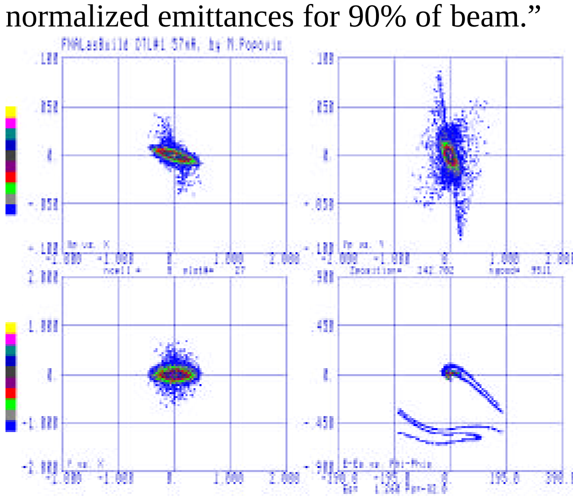
The input beam distribution in the longitudinal plane is a bunch 360 degrees long with a total energy spread of 2 keV. This is supposed to simulate a DC beam with measured energy spread of 2keV. The Twiss, or Courant-Snyder ellipse parameters α and β for each phase plane x-x', y-y', are chosen for best possible transmission from the start to the exit of Tank 5. The input emittances in the x and y plane are 1π mm-mrad normalized.

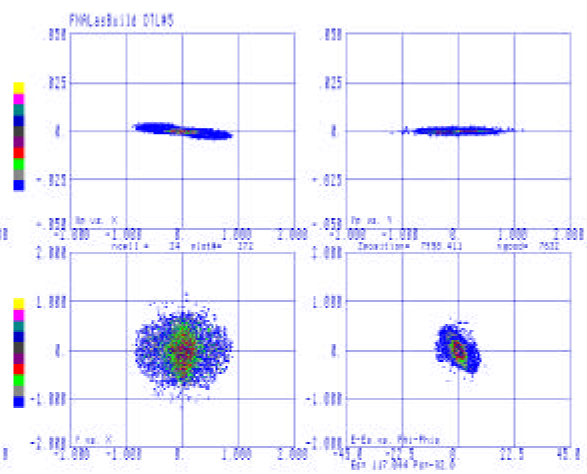
These are emittances traditionally measured using probes at the entrance to Tank1. See Doug Moehs' note in the Linac logbook from 17-Feb-04.
The accuracy of the simulations was checked during the last few months for different settings of various quadrupoles. These changes of quadrupole settings are the result of regular linac tuning. In each case the amount of the beam at the exit of Tank5 and the distribution of losses along the linac were as predicted by PARMILA runs. The following data is included as a typical example of the kind of agreement that has been achieved.



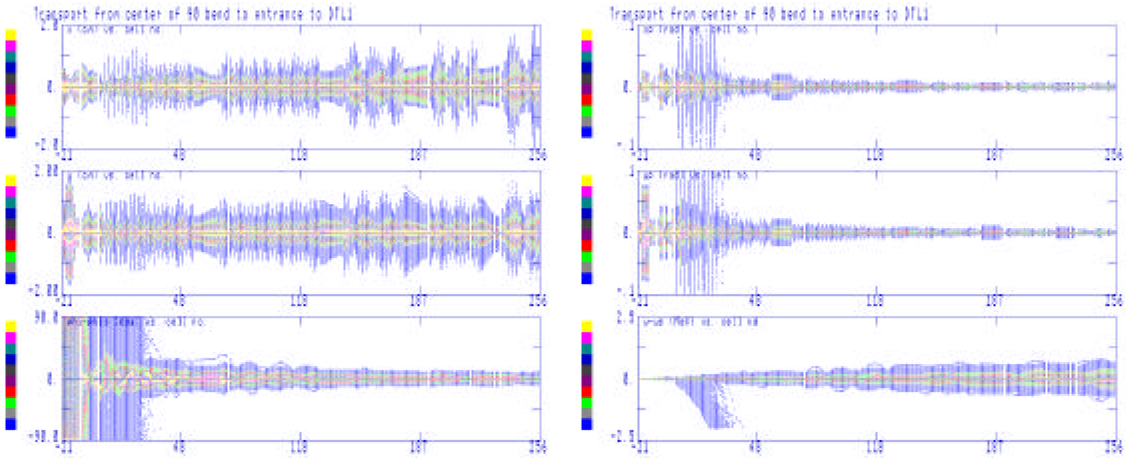


These are toroid readings on March-31-04. At the same time that these reading were recorded, I have recorded quad readings in the transfer line as well as in the five linac tanks. Using these readings PARMILA reports 36.96mA at exit of Tank2 and 36.69mA at exit of Tank5 for an input beam current of 48mA. The 90% normalized emittance at exit of Tank 5 is 7.7 π mm-mrad horizontally and 4.5 π mm-mrad vertically. The horizontal emittance is on the high side comparing with the traditionally measured 5 π mm-mrad, but it is consistent with the higher emittance measured recently at 400 MeV. Here is Linac logbook entry from Feb-12-04. "On 22_jan-04 Larry Allen has recorded wire profiles at the end of linac. Based on these profiles I have calculated emittances using Trace3D. Here are the numbers. E_x=7.1pi mm-mrad, E_y=5.5pi mm-mrad. These are normalized emittances for 90% of beam."





This is a bunch at the exit of drift tube 8 in Tank1. This is a bunch at the exit of Tank 5.



This is beam spread in x, y and phi. This is x', y' and energy spread

The starting point is at the center of the 90-degree magnet, and the ending point is at the exit from Tank 5.

Future Plans

The first thing that will be tried is to match wire profiles at the end of Tank 5 and in the transition section. The next is to extend the simulation to include the CCL linac and the 400MeV transfer line to the Booster. There are several ideas that can be tested using this simulation and their operational impact, (smaller beam in the Booster, reduce losses in the Booster etc.)

- Scrape the beam halo as far upstream as possible,
- Try to remove/reduce the mismatch in Tank3 and later,
- Study the sensitivity to inter-tank phases,
- Resolve the puzzle of much larger emittance in the horizontal plane,
- Study quadrupole/drift-tube misalignments.

References

[1] NUMERICAL RESULTS FROM "PARMILA" FOR THE FIRST TWO TANKS OF LINAC. W.W. Lee and S.C. Snowdon, Fermilab Pub, TM-280, 1970

[2] MOMENTUM SPREAD OF THE 200 MeV LINAC BEAM AT NAL. Shoroku Ohnuma, Fermilab Pub, FN-227, 1971

[3] J.E. Stovall, private communication.

[4] FERMILAB LINAC INJECTOR, REVISITED. By M. Popovic, L. Allen and C. W. Schmidt. Proc. of the 1995 Particle Acc. Conf., Vol. 2, pp. 917.